



Slow extraction from the Debuncher for Mu2e

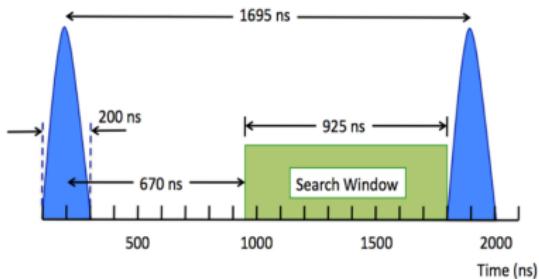
Leo Michelotti
for the Mu2e Extraction Subgroup

James Amundson, Nick Evans, John Johnstone, Vladimir Nagaslaev, Chong Shik Park, Peter Prieto, Steve Werkema

All Experimenters' Meeting
November 7, 2011



Beam objectives

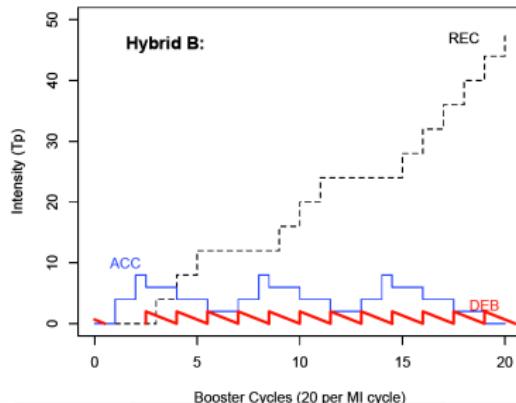
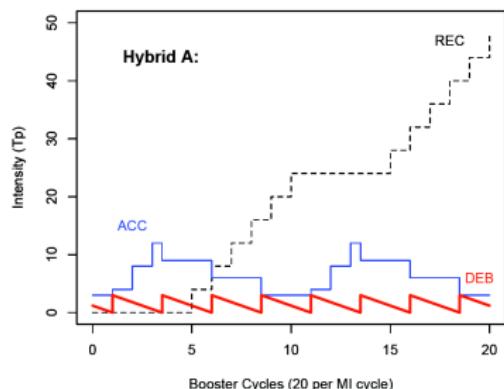


- ▶ 0.25-3 mm spot size on target (1 mm)
- ▶ 10^{-10} out-of-time extinction
- ▶ $\sigma_p/p \approx 0.004$, or less

- ▶ 20-50 nsec rms micropulse: “desired” 30 nsec; ± 100 nsec max; $\sigma \approx 45$ nsec (parabolic)
- ▶ Every 1.7 μ sec (Debuncher cycle time)
- ▶ $\langle dN/dt \rangle \approx 10-25$ Tp/sec
 $dN/dn \approx 30-35$ Mp $\pm 50\%$ (per micropulse)



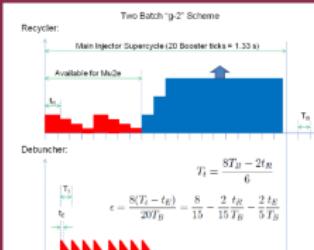
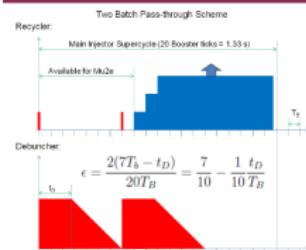
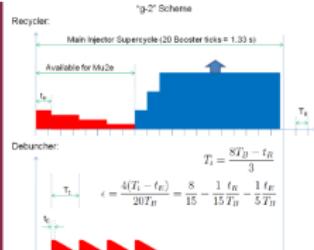
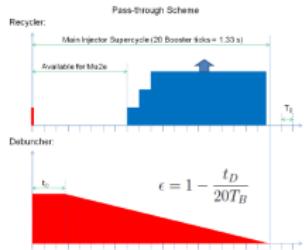
Hybrid-A and Hybrid-B scenarios



- ▶ Using accumulator enabled (almost) continuous spill rate of $\approx 34 \text{ Mp}$ per micropulse, or $\approx 18 \text{ Tp/sec}$.
- ▶ A: $3 \text{ Tp} / 166.67 \text{ msec}$ B: $2 \text{ Tp} / 100 \text{ msec}$, with gap
- ▶ Devised on or before October, 2009 by nonlinear combination of Mike Syphers, Milorad Popovic, Charles Ankenbrandt, and possibly others.
- ▶ Rendered obsolete (too expensive) in August, 2011.



Task Force Scenarios



Symbol	Definition	Likely Range (ms)	Assumed Value (ms)
T_B	Booster "tick"	-	66.7
t_D	Time to capture and condition the beam in the Debuncher in the "Pass-through" scheme	100-500	300
t_R	Time to split Booster batch into 4 bunches in Recycler and prepare for transfer	50-160	90
t_E	Time to prepare each "g-2" bunch for extraction in Debuncher	1-10	5

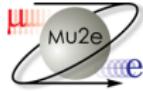
Figures taken from Eric Prebys' presentation,
"Mu2e Task Force Status."
October 6, 2011

See also: Mu2e doc-1866

- ▶ Accumulator not used as staging area; protons injected directly from Recycler into Debuncher.
- ▶ One or two booster batches per supercycle, not six, reduces average spill rate to experiment.
- ▶ Duty factor from 0.25 to 0.78.
- ▶ Other schemes bypassing pbar source entirely put forward but riskier. Would initiate new R&D projects, delaying CD-1 review another year.
- ▶ Currently favored scenario: "two-batch g-2" (lower right corner).



Scenario parameters



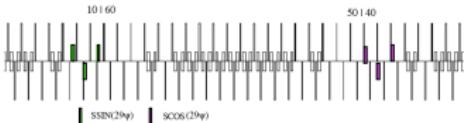
Hybrid-A/B			
$(\Delta p/p)_{\max}$		0.0113 ^(d)	
$(\Delta t)_{\text{rms}}$	nsec	20-50 ^(f)	
Initial emittance	$\pi \text{ mm-mm}$	20-25 / $\beta\gamma$	
Intensity	T _p	3 ^(b) , 2 ^(c)	
Spill time ^(g)	msec	166.67 ^(b) , 100 ^(c)	
N _{turns/spill}		98,328 ^(b) , 58,997 ^(c)	
$\langle dN/dn \rangle$	M _p	30.51 ^(b,d) , 33.9 ^(c,d)	
		34 ^(b,f) , 38 ^(c,f)	
$\langle dN/dt \rangle$	T _p / sec	18 ^(d,h)	
One-batch pass-through			
Intensity	T _p	4	1
Spill time	msec	1033.33 - 1333.33	142.8 - 147.8
N _{turns/spill}		609,667 - 786,667	84,239 - 87,189
dN/dn	M _p	6.6	11.9
dN/dt	T _p / sec	3.9	7.00
$\langle dN/dt \rangle$	T _p / sec	3	3
Duty factor		0.78	0.43
Two-batch pass-through			
Intensity	T _p	4	1
Spill time	msec	166.7 - 466.7	53.9 - 58.9
N _{turns/spill}		98,333 - 275,333	31,795 - 34,744
dN/dn	M _p	40.7	31.5
dN/dt	T _p / sec	24	18.6
$\langle dN/dt \rangle$	T _p / sec	6	6
Duty factor		0.25	0.323



Hardware and separatrices

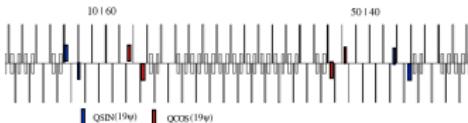


ORTHOGONAL HARMONIC SEXTUPOLE
CIRCUITS FOR 1/3-INTEGER EXTRACTION

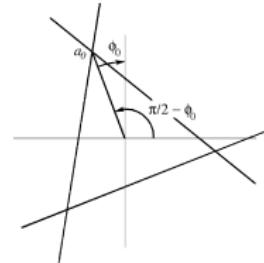


Location of harmonic sextupoles
on two orthogonal circuits for
third-integer extraction

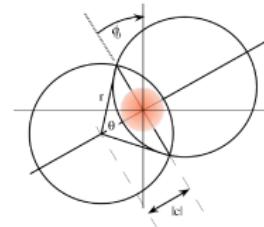
ORTHOGONAL HARMONIC QUADRUPOLE
CIRCUITS FOR 1/2-INTEGER EXTRACTION



Location of harmonic
quadrupoles on two orthogonal
circuits for half-integer
extraction



In normalized phase space, the ideal third-integer separatrix forms an extended equilateral triangle; the half-integer, *if closed*, two isometric circles.

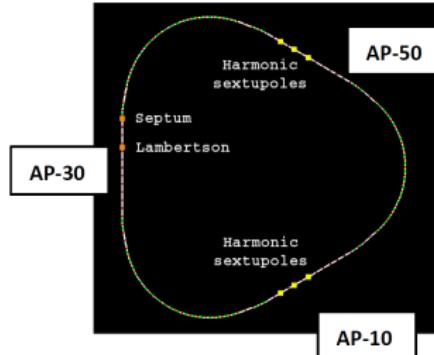




Debuncher's properties



- ▶ Three straight sections designed for zero dispersion.
- ▶ Large dispersion in arcs — $D_x \approx 2$ m — reduces horizontal space charge tune spread.
- ▶ Large horizontal acceptance:
 $\epsilon \approx 35\pi$,
 $\epsilon_{inv} \approx 335\pi$ mm-mm
- ▶ Dihedral symmetry



Two of three Debuncher straight sections to be used for harmonic elements, the third for the septum and lambertson (not necessarily in locations shown)



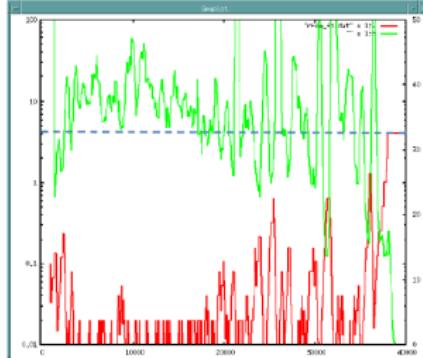
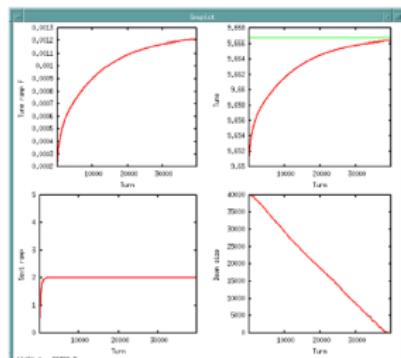
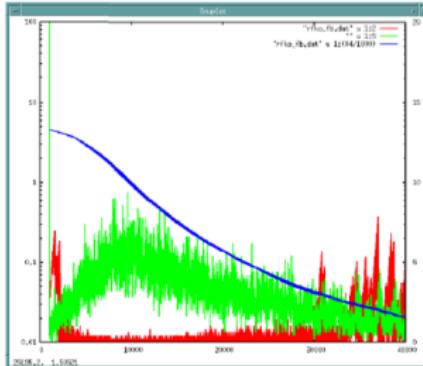
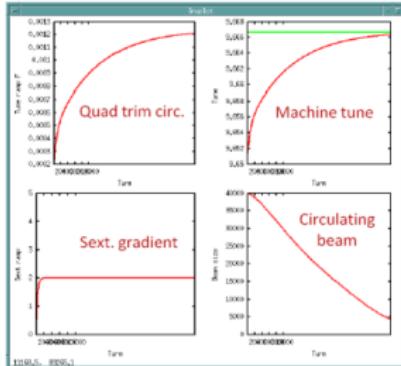
Hardware attributes



- ▶ Fine tune control
 - 3 Quadrupoles: $N \cdot |B' I| \approx 0.8$ Tesla
- ▶ Third-integer resonance extraction
 - 6 Harmonic sextupoles: $N \cdot |B'' I| \approx 900$ T/m
- ▶ Recycled transverse damper for RF knockout
 - $f \approx 393 \pm 6$ kHz
 - $V \approx 400\text{-}600$ Volts
 - $l \approx 1.4$ m
- ▶ Extractors
 - Electric septum: 100 kV across 1.4 cm; $l \approx 2$ m; 50-100 μm wires
 - Magnetic septum (lambertson): 1 Tesla; $l \approx 2$ m; ≤ 1 cm separation
- ▶ Spill diagnostics and regulation
 - 1 msec response time; $\pm 50\%$ micropulse control



Two simulation runs with RFKO





Machine studies



- ▶ Preliminary tune scans carried out in Debuncher to search for parasitic resonances in the machine. (Brian Drendel, Jim Morgan, Steve Werkema)
- ▶ Unfinished half-integer resonance extraction experiments done in Main Injector, without QXR circuit, to be continued. (John Johnstone, Denton Morris, Peter Prieto, Dave Johnson)
- ▶ Ongoing prototyping, design and fabrication, of wall monitor to detect extracted bunches to regulate spill. (Peter Prieto)
- ▶ RFKO study beginning this month in Debuncher using Tevatron style horizontal damper/kicker. (Vladimir Nagaslaev, *et al.*)





More information available



- ▶ Mu2e Collaboration Web Page:
<http://mu2e.fnal.gov>
- ▶ Mu2e Document Database
 - public: <http://mu2e-docdb.fnal.gov/cgi-bin/DocumentDatabase>
 - private: <https://mu2e-docdb.fnal.gov:440/cgi-bin/DocumentDatabase>
- ▶ “Preliminaries toward studying resonant extraction from the Debuncher”: FERMILAB-FN-0842-APC-CD
<http://lss.fnal.gov/archive/test-fn/0000/fermilab-fn-0842-apc-cd.pdf>
- ▶ “Proposal to search for $\mu \rightarrow e$ with a single event sensitivity below 10^{-16} ” FERMILAB-PROPOSAL-0973
<http://lss.fnal.gov/archive/test-proposal/0000/fermilab-proposal-0973.pdf>
- ▶ “Documents on resonant extraction” (Mu2e-doc-768)
<https://mu2e-docdb.fnal.gov:440/cgi-bin>ShowDocument?docid=768>